4 MAJOR ACTIVITIES

In the previous section, we provided a snapshot of the activities we pursue in the Laboratory for Atmospheres. This section presents a more complete picture of our work in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for the National Oceanic Atmospheric Administration's (NOAA) remote-sensing requirements. Section 4 concludes with a listing of our project scientists, a description of our interactions with other scientific groups, and an overview of our efforts toward commercialization and technology transfer.

Measurements

Studies of the atmospheres of our solar system's planets–including our own–require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the ground. Our instrument systems perform one or both of the functions: 1) providing information leading to a basic understanding of the relationship between atmospheric systems and processes; 2) serving as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Balloon and airborne platforms facilitate viewing such atmospheric processes as precipitation and cloud systems from a high-altitude vantage point but still within the atmosphere. Such platforms serve as stepping stones in the development of spaceborne instruments.

Two instrument systems are featured in some detail. The SOLSE/LORE system was designed and developed in the Laboratory and was included in the STS-107 payload that was lost with the tragic loss of the shuttle Columbia. Throughout the flight of Columbia the system performed flawlessly and much data was returned through the real-time downlink.

A second featured instrument is the Cloud Physics Lidar (CPL) system developed for flights on the ER-2 aircraft. This system was used during the CRYSTAL-FACE field campaign. In combination with the Cloud Radar System (CRS), the two instruments produced composite Lidar/Radar profiles of moisture and aerosols through the cloud layers from as high as 19 km to the surface. These flights provided a unique opportunity to demonstrate the potential for combined active sensing systems to provide higher quality scientific data.

Table II follows these articles and shows the principal instruments that have either been built in the Laboratory or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table II also indicates each instrument's deployment–in space, on aircraft, on the ground, or in the laboratory. A brief description of each instrument is given after the table.

The Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)

SOLSE/LORE was included in the STS-107 payload that was lost with the Columbia tragedy. The experiment performed flawlessly during the flight and data was received via the Shuttle downlink. The bulk of data was stored on a hard disk in the Shuttle, and was not recovered. Nevertheless this experiment was a success for STS-107, a story that needs to be told.

The purpose of the SOLSE/LORE experiment was to demonstrate that measurements of limb-scattered sunlight can be used to derive ozone profiles from the stratosphere down to the tropopause with high vertical resolution. SOLSE was an imaging spectrometer that operated in either visible or UV wavelengths, while LORE was a filter radiometer with channels covering UV and visible wavelengths. The two instruments were flown in a single Hitchhiker Jr. GAS can on the shuttle. The instruments, developed at Goddard Space Flight Center, were first flown on STS-87. The SOLSE/LORE STS-107 mission had two purposes: first, to better understand the capability of limb scatter measurements for ozone retrieval over a wide range of conditions, and second, to provide an initial simulation of the performance expected from the Ozone Mapper and Profiler System (OMPS). OMPS is the ozone sounder instrument planned for the National Polar Orbiting Environmental Satellite System (NPOESS).

For flight on STS-107, the instruments were reconfigured in the Laboratory for Atmospheres Radiometric Calibration and Development Facility to simulate the performance expected from OMPS. This mission was partially funded by the Integrated Program Office as a risk mitigation activity for this future ozone measurement instrument. The concept of limb scatter used for ozone measurement is shown in the illustration below.

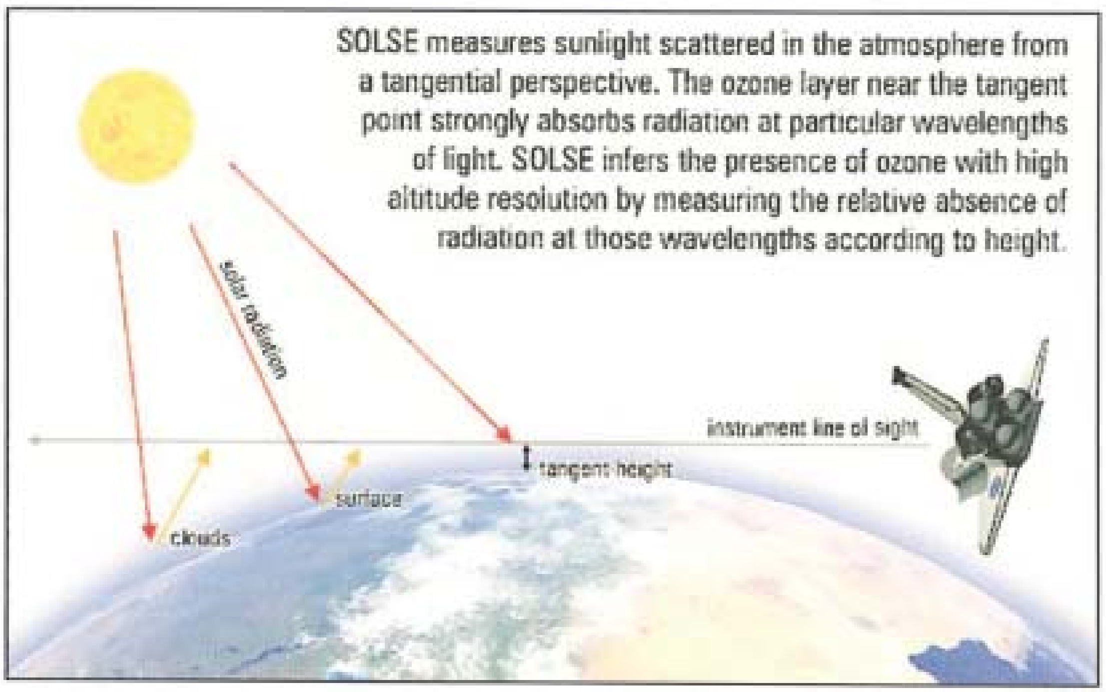

Figure 4-1. Illustration of how ozone is seen using scattered light from the Earth's limb.

SOLSE imaged the limb of the Earth onto a CCD array through a spectrometer, forming a multiwavelength image–530 nm to 850 nm, at 0.7 nm resolution. Shorter wavelengths (near 300 nm), which are highly sensitive to ozone, were used to measure the ozone profile up to 50 km, while longer, less sensitive wavelengths (near 600 nm) measured ozone in the lower stratosphere, possibly down to 10 km.

Optical Design:

SOLSE was a Czerny-Turner imaging spectrometer designed to produce a high-quality image of the limb of the Earth while minimizing internal scattered light. The resolution of the vertical image was better than 1 km. The optical bench layout and major or system specifications are shown below.

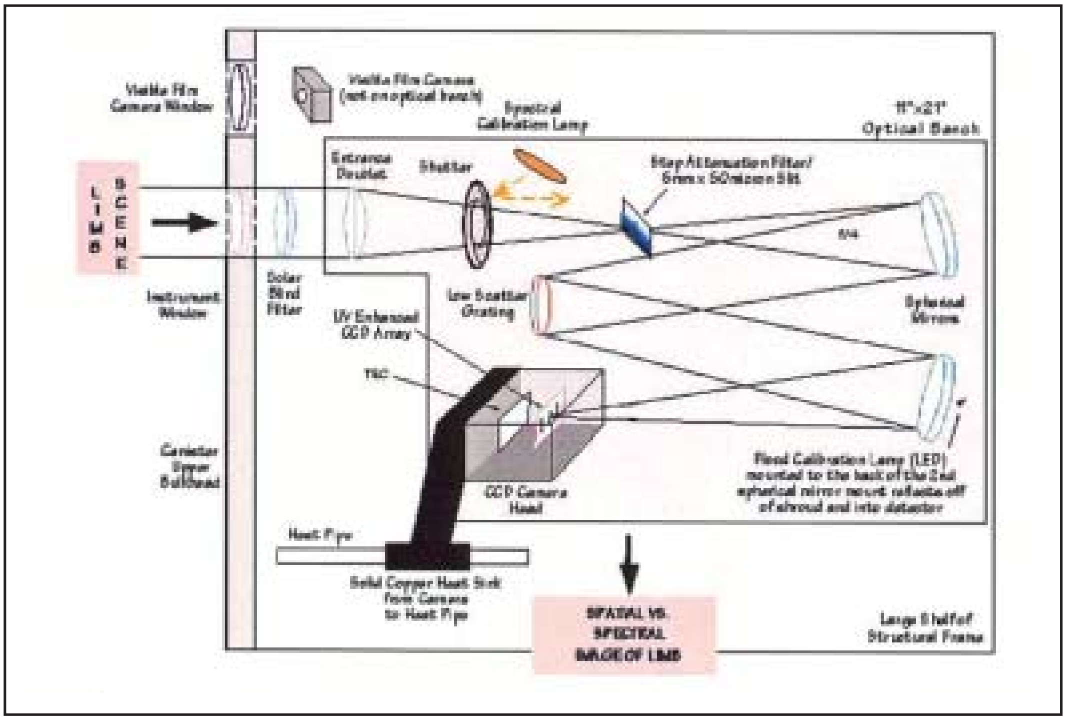

Figure 4-2. Diagram of optical design on the SOLSE instrument.

LORE, the Limb Ozone Retrieval Experiment, was a small camera system that accompanied SOLSE. LORE was a filter radiometer with a linear diode array detector in the SOLSE canister to measure the limb-scattered radiance at ultraviolet and visible wavelengths. LORE had channels at 322, 350, 603, 675, and 760 nm. The 603 nm channel was used to measure ozone in the 15–30 km region using Chappuis band absorption. The channel at 760 nm was used to measure oxygen absorption, while the channel at 322 nm measured ozone above 30 km. The channel at 350 nm provided pointing information. An isometric view of the limb ozone retrieval apparatus is shown below along with key specifications.

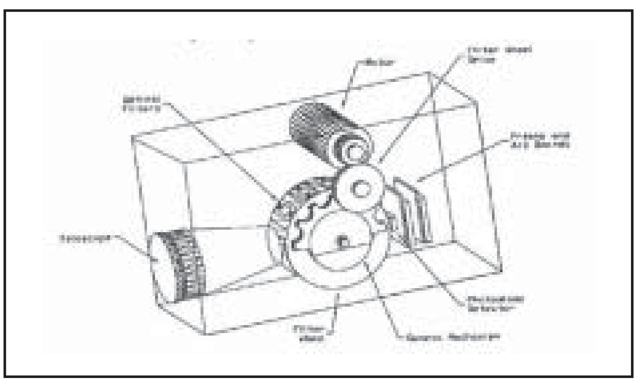

Figure 4-3. Isometric view of the LORE limb ozone retrieval apparatus.

Wavelength	Purpose	Spatial Resolution
322 nm	mid to upper stratospheric ozone	0.5 km
350 nm	pointing channel	0.5 km
603 nm	Chappuis band ozone channel	0.75 km
675 nm	aerosol background channel	0.75 km
760 nm	ozone absorption and pointing	0.75 km

SOLSE and LORE provided the first retrieval of stratospheric ozone by limb scattering as a shuttle payload on STS-87 in 1997. The results from the first flight demonstrated that limb sounding of ozone can achieve 1–3 km altitude resolution down to 15 km. The spectral coverage of SOLSE was changed for the reflight to include visible wavelengths, in addition to UV, to achieve LORE's depth of retrieval which clearly detected the tropopause.

During flight STS-107 the spectra shown below from the 25 km altitude point were measured as the shuttle crossed the terminator moving into sunlight. Note the strong ozone absorption feature near 600 nm that becomes less prominent as the Sun rises higher in the sky. (Raw counts are shown; absolute levels depend on the varying exposure time.)

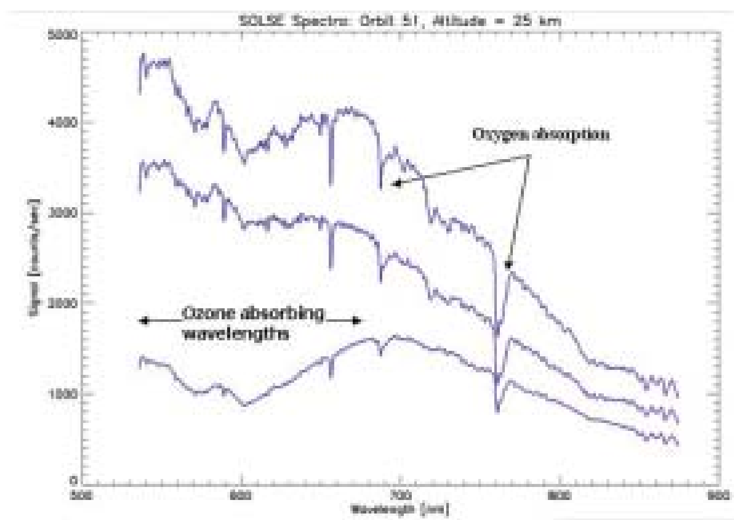

Figure 4-4. SOLSE spectra from the 1st limb-viewing orbit at three different solar zenith angles. The amount of absorption depends on various factors including the solar zenith angle and the particular tangent altitude that is being viewed.

Approximately 70% of the LORE and 12% of SOLSE data was received through the shuttle downlink. Therefore, most of the science objectives were met, such as the goal to demonstrate that limb scattering works over a wide range of latitudes. Preliminary results were presented at a scientific conference in April 2003 and a publication is expected before the end of the year. For more information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

Cloud Physics Lidar

One of the most important components of airborne remote-sensing experiments is the high altitude NASA ER-2 aircraft. Because the ER-2 typically flies at about 65,000 feet (20 km), its instruments are above 94% of the Earth's atmosphere, allowing ER-2 instruments to function as spaceborne instrument simulators. The ER-2 provides a unique platform for atmospheric profiling, particularly for active remote-sensing instruments such as lidar, because the spatial coverage attainable by the ER-2 permits studies of aerosol properties across wide regions. Lidar profiling from the ER-2 platform is especially valuable because the cloud height structure, up to the limit of signal attenuation, is unambiguously measured.

The Cloud Physics Lidar, or CPL, is a backscatter lidar designed to operate simultaneously at 3 wavelengths: 1064, 532, and 355 nm. The purpose of the CPL is to provide multiwavelength measurements of cirrus, subvisual cirrus, and aerosols with high temporal and spatial resolution. Figure 4-5 shows the optical bench, which is the heart of the instrument, while Figure 4-6 shows the entire CPL package in flight configuration. The CPL utilizes state-of-the-art technology with a high repetition rate, low pulse energy laser and photon-counting detection. Vertical resolution of the CPL measurements is fixed at 30 m; horizontal resolution can vary but is typically about 200 m. Primary instrument parameters are listed in the table below. The CPL fundamentally measures range-resolved profiles of volume 180-degree backscatter coefficients. From the fundamental measurement, various data products are derived, including time-height cross-section images; cloud and aerosol layer boundaries; optical depth for clouds, aerosol layers, and planetary boundary layer (PBL); and extinction profiles.

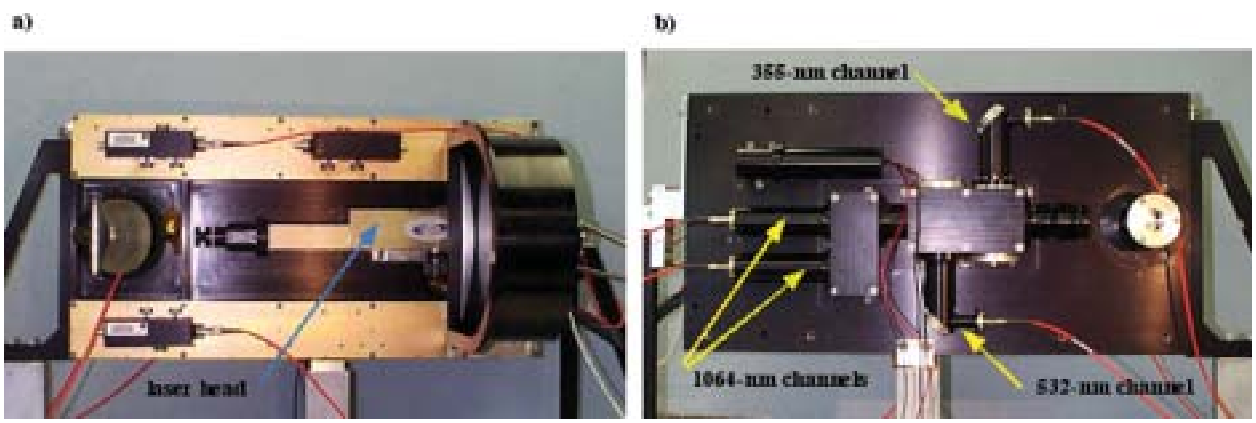

Figure 4-5. a) Photo of transmitter side of CPL optical bench, showing laser head and off-axis mirror. b) Photo of receiver side of CPL optical bench, showing the component layout and the different wavelength channels.

Figure 4-6. Photo of the CPL in flight configuration. The optical bench, shown in Figure 4-5, resides inside the blue box (top) to keep the optics clean, dry, and thermally stable. The entire package slides into the ER-2 wing pod.

CPL system parameters

PARAMETER	VALUE
Wavelengths	1064, 532, and 355 nm
Laser type	solid-state Nd:YVO_4
Laser repetition rate	5 kHz
Laser output energy	50 µJ at 1064 nm 25 µJ at 532 nm 50 µJ at 355 nm
Telescope	20 cm diameter, off-axis parabola
Telescope field of view	100 microradians, full angle
Effective filter bandwidth (full width, half-height)	240 pm at 1064 nm 120 pm at 532 nm 150 pm at 355 nm
Raw data resolution	1/10 second (30 m vertical by 20 m horizontal)
Processed data resolution	1 second (30 m vertical by 200 m horizontal)

The CPL provides information to permit a comprehensive analysis of radiative and optical properties of optically thin clouds. Primary data products include:

- Cloud profiling with 30 m vertical and 200 m horizontal resolution at 1064 nm, 532 nm, and 355 nm, providing cloud location and internal backscatter structure.

- Aerosol, boundary layer, and smoke plume profiling at all three wavelengths, providing calibrated profiles of backscatter coefficients.

- Depolarization ratio to determine the phase (e.g., ice or water) of clouds using the 1064 nm output.

- Determination of optical depth for both cloud and aerosol layers (up to the limit of signal attenuation, ~ optical depth 3).

- Determination of extinction-to-backscatter parameter.

The CPL uses photon-counting detectors with a high repetition rate laser to maintain a large signal dynamic range. This dramatically reduces the time required to produce reliable and complete data sets. The CPL analysis provides data within 24 hours of a flight including: (1) cloud and aerosol quick-look pictures, (2) cloud and aerosol layer boundaries, and (3) depolarization information. The optical depth determinations require more careful analysis. Determination of optical depths for uncomplicated layers of cirrus clouds with homogeneous scattering characteristics can be completed within a day using an automated analysis algorithm. However, situations where the cloud layering and structure is complex, which often precludes an automated data processing algorithm, may require several weeks for processing. The ability to produce data products in near-real time has proven invaluable during field campaigns.

The fundamental CPL data product is a time-height cross-section image of the atmosphere, as illustrated in Figure 4-7. Data shown in Figure 4-7 is a 3-1/2 hour segment of data from the CRYSTAL-FACE experiment on July 26, 2002.

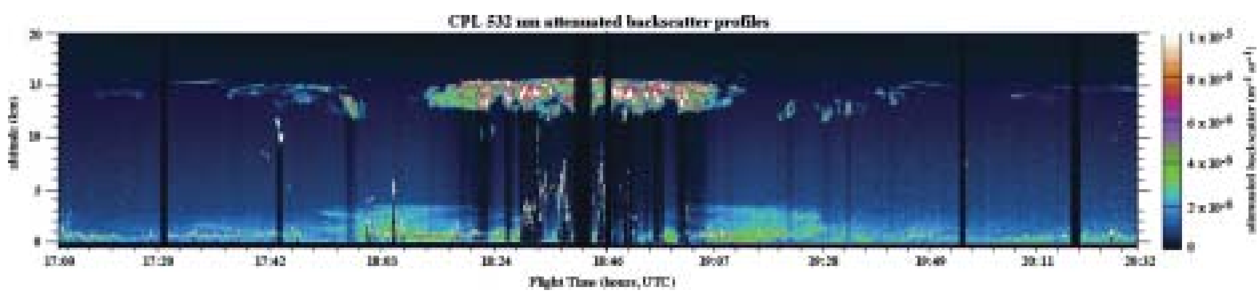

Figure 4-7. Example of CPL data. This image shows profiles of 532 nm attenuated backscatter from July 26, 2002. This image is representative of airborne lidar data, showing cloud height and internal structure and boundary layer aerosol. In addition, a period of elevated aerosol, known to be Saharan dust, is evident in the middle of the time period.

To date the CPL has participated in several field campaigns, including:

SAFARI-2000 (Pietersburg, South Africa, August–September 2000)

CRYSTAL-FACE (Key West, Florida, July 2002)

TX-2002 (San Antonio, Texas, November–December 2002)

THORPEX (Honolulu, Hawaii, February–March 2003)

For more information about the CPL or CPL data products, please visit the CPL Web site at http://virl.gsfc.nasa.gov/cpl or contact Matthew McGill (Matthew.J.McGill@nasa.gov).

Table 2. Principal Instruments Supporting Scientific Disciplines in the Laboratory for Atmospheres

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation	Planetary Atmospheres/Solar Influences
Space		Total Ozone Mapping Spectrometer (TOMS) - Earth Probe (EP) Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) Earth Polychromatic Imaging Camera (EPIC) - Triana (renamed DSCOVR)		Gas Chromatograph Mass Spectrometer (GCMS) – Cassini Huygens Probe Ion and Neutral Mass Spectrometer (INMS) – Cassini Orbiter Neutral Mass Spectrometer (NMS) – *Nozomi* Neutral Gas and Ion Mass Spectrometer (NGIMS) – Comet Nucleus Tour (CONTOUR)
Aircraft	ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) Raman Airborne Spectroscopic Lidar (RASL)	Cloud Physics Lidar (CPL) cloud THickness from Offbeam Returns (THOR) Lidar Leonardo Airborne Simulator (LAS) Cloud Radar System (CRS)	
Ground/ Laboratory/ Development	Scanning Raman Lidar (SRL) Goddard Lidar Observatory for Winds (GLOW) Lightweight Rainfall Radiometer (LRR-X)	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) Aerosol and Temperature Lidar (AT Lidar) Brewer UV Spectrometer Goetz Radiometer Aerosol Lidar (AL) L2-SVIP	Micro-Pulse Lidar (MPL) Scanning Microwave Radiometer (SMiR) Sun-Sky-Surface photometer (3S) COmpact Vis IR (COVIR) Surface-sensing Measurements for Atmospheric Radiative Transfer (SMART)-Chemical, Optical and Microphysical Measurements of In situ Troposphere (COMMIT)	

Spacecraft-Based Instruments

The Total Ozone Mapping Spectrometer (TOMS) on Earth Probe (EP) continues to provide daily mapping and long-term trend determination of total ozone, surface UV radiation, volcanic SO_2, and UV-absorbing aerosols since 1996. For further information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

The Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE) measures ozone profiles from the stratosphere down to the tropopause with high vertical resolution. SOLSE is a grating spectrometer that operates in the UV and visible wavelengths while LORE is a filter radiometer with channels in the UV and visible wavelengths. The instruments have been reconfigured in the Laboratory for Atmospheres' Radiometric Calibration and Development Facility (RCDF) to more accurately simulate the performance expected from the Ozone Mapper and Profiler System (OMPS) where both will measure high vertical resolution profiles in the stratosphere down to the tropopause. The OMPS is the ozone sounder instrument which will fly on the National Polar Orbiting Environmental Satellite System (NPOESS) and the NPP (NPOESS Preparatory Project). See the instrument above for more details on SOLSE/LORE. For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath-1@nasa.gov), or Richard McPeters (Richard.D.McPeters@nasa.gov).

Earth Polychromatic Imaging Camera (EPIC) on Triana (renamed DSCOVR) is a 10-channel spectroradiometer spanning the ultraviolet (UV) to the near-infrared (IR) wavelength range (317.5 to 905 nm). The main quantities measured are (1) column ozone, (2) aerosols (dust, smoke, volcanic ash, and sulfate pollution), (3) sulfur dioxide, (4) precipitable water, (5) cloud height, (6) cloud reflectivity, (7) cloud phase (ice or water), and (8) UV radiation at the Earth's surface. We will also measure other quantities related to vegetation, bidirectional reflectivity (hotspot analysis) and ocean color. EPIC has two unique characteristics: (1) EPIC takes the first spaceborne measurements from sunrise to sunset of the entire sunlit Earth and (2) EPIC performs the first simultaneous measurements in both the UV and visible wavelengths. These capabilities will allow us to determine diurnal variations and permit extended measurements of aerosol characteristics (2002). The Triana spacecraft and instruments are complete and tested for flight; however, they are temporarily in storage awaiting a flight opportunity. Recent work has improved the scattered light rejection capability to improve the instrument's signal to noise capabilities. For further information, contact Jay Herman (Jay.R.Herman@nasa.gov).

The Gas Chromatograph Mass Spectrometer (GCMS) for the Cassini Huygens Probe will measure the chemical composition of gases and aerosols in the atmosphere of Titan (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann@nasa.gov).

The Ion and Neutral Mass Spectrometer (INMS) on Cassini Orbiter will determine the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of its icy satellites (1997), starting in 2004. For further information, contact Hasso Niemann (Hasso.B.Niemann@nasa.gov).

The Neutral Mass Spectrometer (NMS) on the Japanese spacecraft Nozomi (Planet-B) will measure the composition of the neutral atmosphere of Mars to improve our knowledge and understanding of the energetics, dynamics, and evolution of the Martian atmosphere. The Nozomi spacecraft and mission were developed by the Japanese Institute of Space and Astronautical Science (1998). For further information, contact Hasso Niemann (Hasso.B.Niemann@nasa.gov).

The Atmospheric Experiment Branch delivered the Neutral Gas and Ion Mass Spectrometer (NGIMS) to Johns Hopkins University Applied Physics Laboratory on December 10, 2001, for integration onto the CONTOUR spacecraft. CONTOUR was launched on July 3, 2002, and performed flawlessly throughout the first month of spacecraft and instrument checkouts. Unfortunately, the spacecraft was destroyed at the end of the Solid Rocket Motor 50-second burn that was required to send the spacecraft into a trajectory needed for the comet encounter. Telescopic images confirmed the spacecraft had broken up into at least three pieces. For further information, contact Paul Mahaffy (Paul.R.Mahaffy@nasa.gov).

Aircraft-Based Instruments

The ER-2 Doppler Radar (EDOP) is an X-band (9.6 GHz) system which measures vertical profiles of rain and winds within precipitation systems. It has been used for validation of spaceborne rain measurement algorithms used in TRMM and for providing improved understanding of the structure of mesoscale convective systems, hurricanes, and convective storms. It has been involved in 8 major field campaigns with the ER-2, including 3 TRMM validation efforts, 4 CAMEX convection and hurricane campaigns, and CRYSTAL-FACE. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield@nasa.gov).

The Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) measures cloud and aerosol structure in three dimensions via laser backscatter at a wavelength of 1064 nm. Utilizing a unique scanning holographic telescope, this compact lidar fits into small aircraft as well as in a ground-based trailer for field experiment deployments. HARLIE was used in several field experiments including HARGLO, ARMIOP2000, and IHOP. Technical descriptions of the instrument and examples of data products are described at http://harlie.gsfc.nasa.gov/. For further information, contact Geary Schwemmer (Geary.K.Schwemmer@nasa.gov).

The GSFC Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) is a two wavelength lidar system (308 nm and 355 nm) that detects two elastically scattered wavelengths and N2-Raman scattered radiation at 332 nm and 387 nm. The system uses 20 data channels spread over the four detected wavelengths. The instrument was on board the DC-8 during the SOLVE campaign in the winter of 1999/2000. Colleagues at NASA Langley Research Center contributed data channels for depolarization measurements at 532 nm and channels for aerosol backscatter at 1064 nm. Data products are aerosol backscatter and vertical profiles of ozone and temperature. This instrument was installed on the DC-8 in November–December 2002 for a SAGE III Validation campaign flown from Kiruna, Sweden, during January 2003. For further information, contact Thomas McGee (Thomas.J.McGee@nasa.gov).

The Raman Airborne Spectroscopic Lidar (RASL) was developed under NASA's Instrument Incubator Program (IIP). The instrument was laboratory tested on September 18, 2002, for a 24-hour measurement period that demonstrated all claimed capabilities including daytime and nighttime measurements of water vapor mixing ratio, aerosol backscatter coefficient/extinction/depolarization, extinction to backscatter ratio and liquid water scattering (night only), which offers the possibility of retrieving cloud droplet properties such as liquid water content, droplet radius and number density. For further information contact David Whiteman (David.N.Whiteman@nasa.gov).

The Cloud Physics Lidar (CPL) measures cloud and aerosol properties from on board the high-altitude ER-2 aircraft. CPL data is often combined with data from multispectral visible and infrared imaging radiometers to enable studies of atmospheric radiative properties. During 2002, CPL participated in the CRYSTAL-FACE field campaign and a MODIS validation campaign. In 2003, the CPL will be used for GLAS validation activities. For further information, contact Matthew McGill (Matthew.J.McGill@nasa.gov).

The cloud THickness from Offbeam Returns (THOR) is a Lidar operating at 540 nm with Nd-YALO 250 micro Joule Laser pulses. The system detects 8 annular fields of view (FOV's) of diameters increasing by factors of 2 from a single fiber seeing 215 micro radian laser pulses, up to the full 6 degrees (0.1 radians) FOV seen by a fiber bundle containing more than 100,000 fibers connected to an array of Hamanaso single-photon counting detectors. The THOR system provides an inexpensive alternate approach to measuring cloud vertical structure, that eventually can be carried out on unmanned aircraft (UAVs) and perhaps even in space. The reflected "halo" measured by THOR is now being employed in retrieval of cloud properties, using a “nonlocal” approach that improves on the usual “independent pixel approximation” used for standard EOS products. The THOR validation campaign took place in March 2002 over the DOE ARM site in northern Oklahoma. For further information, contact Robert Cahalan (Robert.F.Cahalan@nasa.gov).

The `Leonardo Airborne Simulator (LAS)` is an imaging spectrometer (hyperspectral) with moderate spectral resolutions. LAS measures reflected solar radiation to retrieve atmospheric properties such as column water vapor amount, aerosol loadings, cloud properties, and surface characteristics. This was successfully deployed in the SAFARI-2000 campaign in the vicinity of South Africa. The instrument participated in the July 2002 CRYSTAL-FACE campaign in Florida. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

The `Cloud Radar System (CRS)` is a W-band (94 GHz) millimeter-wave Doppler radar system for measuring cirrus clouds and precipitation regions with lower reflectivities (smaller particles) than detectable with conventional rain radars. The system is designed for high-altitude ER-2 operation and operates at the same frequency as the CLOUDSAT radar. The instrument first flew in the CRYSTAL-FACE field campaign during July 2002. For further information, contact Gerald Heymsfield (Gerald.M.Heymsfield@nasa.gov).

Ground-Based and Laboratory Instruments

The `Scanning Raman Lidar (SRL)` is a mobile, all-weather Raman lidar system that measures the water vapor aerosols and cloud structure. The SRL was deployed to western Oklahoma during May–June 2002 for the International H2O Project (IHOP). Over the course of the 6-week campaign, the SRL was used to record atmospheric evolution during the passage of drylines, fronts and low-level jets. For further information, contact David Whiteman (David.N.Whiteman@nasa.gov).

The `Goddard Lidar Observatory for Winds (GLOW)` is a mobile direct-detection Doppler lidar system that measures vertical profiles of wind from the surface to the stratosphere. The instrument measures winds using the laser energy backscattered from aerosols (wavelength=1064 nm) or molecules (wavelength=355 nm). The 1064 nm-channel data products are high spatial resolution wind profiles in the planetary boundary layer (altitudes < 2km) and the 355 nm channel provides wind profiles in the free troposphere and stratosphere (altitudes as high as 35 km). In the spring of 2002, GLOW was deployed to the Oklahoma panhandle for 8 weeks of intensive measurements as part of the International H_2O Project (IHOP). For further information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

The `Lightweight Rainfall Radiometer/X-band (LRR-X)` is an instrument development project supported by the Instrument Incubator Program (IIP). The radiometer employs an advanced technology design based on the use of a thinned array, synthetic aperture antenna. The antenna consists of a set of linear wave guides producing an interferrometric representation of the X-band (10.7 GHz) wave pattern over a cross-track imaging domain. MIMC receiver and digital correlator technologies are used to process the transmitted wave field. This type of design is referred to as a Synthetic Thinned-Array Radiometer (STAR) having the advantage of not requiring a scanning antenna assembly or a feed horn palette. The instrument will undergo its initial airborne flight testing campaign in the early summer of 2003. For further information, contact Eric A. Smith (Eric.A.Smith@nasa.gov).

The `Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE)` measures vertical profiles of ozone, aerosols, and temperature. The system collects elastically and Raman-scattered returns using Differential Absorption Lidar (DIAL). The instrument has participated in over a dozen international measurement campaigns, and is currently deployed to Mauna Loa Observatory, Hawaii. A water vapor channel is being added for testing at this site in spring 2003. For further information, contact Thomas McGee (Thomas.J.McGee@nasa.gov).

The Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) instrument, developed in the Atmospheric Chemistry and Dynamics Branch, was completed and a final report was submitted to the Earth Science Technology Office (ESTO). The primary objective was to demonstrate the capability for high-resolution measurements of NO_2, SO_2, aerosol, and O_3. The core design is a wide field-of-view (FOV) front-end telescope that illuminates a filter/focal plane array (FFPA) package. For further information, contact Scott Janz (Scott.J.Janz@nasa.gov).

The Aerosol and Temperature Lidar (AT Lidar) is a trailer-based instrument that makes measurements of vertical profiles of atmospheric aerosols and stratospheric temperature. Aerosol information is gathered at three wavelengths to provide particle size information. This instrument has been modified to include water vapor and in-cloud temperature capabilities. Measurements are currently being taken at GSFC. For further information, contact Thomas J. McGee (Thomas.J.McGee@nasa.gov).

The Brewer UV Spectrometer is an operational ground instrument for ozone and UV irradiance measurements. There are several deployed in ozone ground-based networks. The Goddard Brewer instrument has improved calibration and operability for special field campaigns for use as a reference for other network brewer instruments. The instrument is also upgraded to conduct research as part of the Skyrad program. For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath-1@nasa.gov).

Goetz Radiometer is a ruggedized filter UV radiometer with precision filters and electronics for unattended field use for total and profile ozone and UVB irradiance measurements. The long-term objective is to collect accurate ozone and UV data with low cost, reliable and highly accurate hardware. It is also being used to conduct aerosol research as part of the Skyrad program and in conjunction with GSFC's Aeronet program. For further information, contact Ernest Hilsenrath (Ernest.Hilsenrath-1@nasa.gov).

The Aerosol Lidar (AL) is a collaborative effort with JPL to build and deploy a small autonomous aerosol lidar for the Network for the Detection of Stratospheric Change. This lidar will transmit 1064 and 532 nm and will retrieve ozone profiles from both those wavelengths. It will also provide depolarization information to determine the physical state of aerosol particles. The first deployment of the lidar will be to a remote site on Christmas Island, near the equator, south of Hawaii. Data will be collected as continuously as possible for a year to gather information on the cloud climatology above the island. For further information, contact Thomas McGee (Thomas.J.McGee@nasa.gov).

L2-SVIP (Lagrange-2 Solar Viewing Interferometer Prototype) is a new prototype instrument being developed to demonstrate the technology needed to develop large aperture (8 to 10 meters) interferometers needed for observing the Earth's atmosphere at Lagrange-2 (1.5 million kilometers behind the Earth on the Earth-Sun line). This development is being done under a new IIP project in cooperation with Code 916 and Code 930 scientists and Code 500 engineers. The goal of the spaceflight instrument is to map out the altitude, latitude and longitude distribution of the greenhouse gases (CO_2, H_2O, CH_4, HCl, O_3, O_2). For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

The Micro-Pulse Lidar (MPL) system is a compact and eye-safe lidar capable of determining the range of aerosols and clouds continuously in an autonomous fashion. The MPL was developed at GSFC during the early 1990s and is now a commercial product. The unique capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. In 2000, the Micro-Pulse Lidar Network (MPLNET) was begun. MPLNET is comprised of ground-based MPL systems, co-located with sun/sky photometer sites in the NASA Aerosol Robotic Network (AERONET). The MPLNET project is discussed in more detail in section 5. For further information on MPL systems, contact James Spinhirne (James.D.Spinhirne@nasa.gov) and for questions on the MPLNET project, contact Judd Welton (Ellsworth.J.Welton@nasa.gov).

The Scanning Microwave Radiometer (SMiR) measures the column amounts of water vapor and cloud liquid water using discrete microwave frequencies. This instrument was successfully deployed in SAFARI-2000, in ACE-Asia-2001, and in CRYSTAL-FACE-2002 campaigns. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

The Sun-Sky-Surface photometer (3S) is under development in collaboration with Biophysics Branch (Code 923) and Detector System Branch (Code 553). The 3S contains 14 discrete channels, ranging from the ultraviolet to shortwave-infrared spectral region, and scans the upper (atmosphere) and lower (surface) hemispheres during its operation. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

COmpact Vis IR (COVIR) is an engineering model of an imaging radiometer for small satellite missions. The instrument is being developed under the Instrument Incubator Program (IIP) and will measure visible and IR wavelengths in the following ranges: 10.3-11.3 µm, 11.5-12.5 µm, 9.5-10.5 µm, and 0.67-0.68 µm. The system employs uncooled microbolometer focal plane detectors. The goal of COVIR is to enable future multisensor Earth science missions to utilize smaller and lower cost infrared and visible imaging radiometers. This will lead to improved cloud sensing through increased spatial resolution and coverage with spectral IR data. The design of COVIR is complete. Analysis was completed and a paper published on the results of infrared stereo cloud height retrieval by data acquired during the Infrared Spectral Imaging Radiometer shuttle hitchhiker experiment. For further information, contact James Spinhirne (James.D.Spinhirne@nasa.gov).

SMART-COMMIT is a new combination of two suites of instruments. The Surface-sensing Measurements for Atmospheric Radiative Transfer (SMART) is a suite of surface remote-sensing instruments developed and mobilized to collocate with satellite overpass at targeted areas for retrieving physical/radiative properties of the Earth's atmosphere and for characterizing surface properties. The SMART includes an array of broadband radiometers, a shadow-band radiometer, a sunphotometer, a solar spectrometer, a whole-sky camera, a micro-pulse lidar, and a microwave radiometer, as well as meteorological probes for atmospheric pressure, temperature, humidity, and wind speed/direction. During past years, SMART has been deployed in many NASA-supported field campaigns to collocate with satellite nadir overpass for intercomparisons, and for initializing model simulations. Built on the successful experience of SMART, we are currently developing a new ground-based in situ sampling package, Chemical, Optical and Microphysical Measurements of In situ Troposphere (COMMIT). COMMIT includes measurements of trace gas (CO, NO_x, SO_2, and O_3) concentrations, fine/coarse particle size and chemical composition, single- and three-wavelength nephelometers. The next major activities for SMART-COMMIT are scheduled for FY03–05 in BASE-ASIA (Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment) and CHINA-TEA (Climate & Health Impacts in Northeast Asia-Tropospheric Experiment on Aerosols). For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

Field Campaigns

Field campaigns typically use the resources of NASA, other agencies, and other countries to carry out scientific experiments or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2 and DC-8, serve as platforms from which remote-sensing and in situ observations are made. Ground systems are also used for soundings, remote sensing and other radiometric measurements. In 2002, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases. The IHOP and CRYSTAL-FACE were two major campaigns supported this year by Laboratory scientists and engineers.

International H_2O Project (IHOP-2002)

The International H_2O Project (IHOP-2002) was a major field experiment conducted in May–June 2002 over the southern Great Plains to explore improved water vapor measurements and their incorporation in forecast models. The Scanning Raman Lidar (SRL), the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) and the Goddard Mobile Lidar Observatory for Wind (GLOW) were deployed for IHOP-2002. SRL provided profiles of water vapor mixing ratio to reveal the water vapor stratification to altitudes of 10 km or more. HARLIE provided data characterizing Atmospheric Boundary Layer structure and winds. GLOW provided measurements of wind speed and direction from the surface into the stratosphere. Further details on the IHOP campaign are found in Section 5 highlights under the Mesoscale Atmospheric Processes Branch section.

CRYSTAL-FACE

Members of the Laboratory for Atmospheres played key roles in the Cirrus Regional Study of Tropical Anvils and Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE), a major NASA field experiment conducted in south Florida in July 2002. There were six aircraft participating in CRYSTAL-FACE: NASA's ER-2 and WB-57, the Proteus (contracted by IPO), the University of North Dakota Citation, Naval Research Laboratory's P-3 and CIRPAS Twin Otter. The aircraft were based at Key West Naval Air Facility where the science team of over 200 members was assembled. Important objectives were: 1) the validation of ground-based and satellite remote-sensing observations of cloud properties including observations from Terra (MODIS, MISR, CERES), Aqua (MODIS, AIRS, CERES), GOES, POES, and TRMM (Precipitation Radar); and 2) to provide data sets supporting algorithm development for future measurements from space such as lidar (CALIPSO) and millimeter wavelength radar (CloudSat)–key elements of NASA's "A-Train" that will be in place in 2004. Further details on the CRYSTAL-FACE campaign are found in Section 5 highlights under the Mesoscale Atmospheric Processes Branch section.

Scientists from Code 916 participated in two **International NDSC Comparisons** during 2002. These campaigns are part of a continuing validation protocol within the NDSC. The Network for the Detection of Stratospheric Change (NDSC) consists of a set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the stratosphere. The first campaign was held at Lauder, New Zealand, and involved scientists from the Netherlands, New Zealand, and the United States. The second campaign was held at the NOAA facility at Mauna Loa Observatory, Hawaii, in August 2002. This campaign involved instruments from NRL, Goddard, JPL and NOAA. Goddard participants from the Atmospheric Chemistry and Dynamics branch included Tom McGee, with his stratospheric ozone lidar system, and Richard McPeters, who served as the referee for the comparison. Ozone profiles (15 to 50 km) and temperature profiles (15 to 80 km) were compared over a 16-day period. Both of these campaigns were designed to validate data quality of instruments permanently operated at the sites, and included profile measurements of ozone, temperature and aerosols. For further information, contact Thomas McGee (Thomas.J.McGee@nasa.gov), or Richard McPeters (Richard.D.McPeters@nasa.gov).

Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns is used directly in scientific studies. Some of the data from our instruments and campaigns, plus data from additional sources, are arranged into data sets useful for studying various atmospheric phenomena. Some of these data sets are described in the following paragraphs.

TIROS Operational Vertical Sounder Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is the TIROS Operational Vertical Sounder (TOVS). TOVS is comprised of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 to the present, using an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2002 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount and cloud height, OLR and clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, NOAA 6,7,8,9,10,11,12, and 14. Equivalent future data sets will be produced from NOAA 16 and 17 ATOVS data and from AIRS data on EOS Aqua. We have demonstrated that TOVS data can be used to study interannual variability of surface and atmospheric temperatures and humidity, cloudiness, OLR, and precipitation. We have developed the 24-year TOVS Pathfinder Path A data set. The TOVS precipitation data is being incorporated in the monthly and daily GPCP precipitation data sets. We are developing improved methodologies to analyze ATOVS data to produce a future climate data set. We have also developed the methodology to be used by the AIRS science team to generate products from AIRS for weather and climate studies. In joint work with the DAO, the AIRS sounding products will be assimilated into the DAO GEOS 3 system to demonstrate how well the AIRS data will improve weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Total Ozone

The merged satellite total ozone data set was recently updated. Calibration of the original six satellite instruments was transferred to the NOAA 16 SBUV/2. This allows extending the record despite issues with the calibration of the Earth Probe TOMS for the last year or so. The data sets now extend through the end of 2001. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. These data should be useful for trend analyses. For more information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Hollandsworth Frith (smh@code916.gsfc.nasa.gov).

Tropospheric Ozone Data

Tropospheric column ozone (TCO) and stratospheric column ozone (SCO), gridded data products are made available from NASA Goddard Space Flight Center Code 916 via either direct ftp, World Wide Web, or electronic mail. Monthly averaged TCO and SCO data are derived in the tropics for January 1979–present using the Convective Cloud Differential (CCD) method [Ziemke et al., *J. Geophys. Res*., **103**, 22115-22127, 1998]. Specific details regarding algorithm and data are discussed in Ziemke et al. [*Bull. Amer. Meteorol. Soc*., **81**,580-583, 2000; *J. Geophys. Res*., 9853-9867, 2001]. Since 1998 and prior to year 2003, the CCD data have been used in ten published papers. The CCD data, algorithm description, and data documentation may be obtained via World Wide Web at http://hyperion.gsfc.nasa.gov/Data_services/Data.html. For more information, contact Jerry Ziemke (ziemke@jwocky.gsfc.nasa.gov).

Aerosol Products from the Total Ozone Mapping Spectrometer

Laboratory scientists are generating a unique new data set of atmospheric aerosols by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by the TOMS. Since 1996, Laboratory staff members have developed techniques for extracting aerosol information from measured UV radiances. The UV technique differs from conventional visible methods in that the UV measurements can reliably separate UV absorbing aerosols (such as desert dust and smoke from biomass burning) from nonabsorbing aerosols (such as sulfates, sea-salt, and ground-level fog). In addition, the UV technique can measure aerosols over land and can detect all types of aerosols over snow/ice and clouds.

TOMS aerosol data are currently available in the form of a contrast index (and now as optical depth). The aerosol index, AI, provides excellent information about sources, transport, and seasonal variation of a variety of aerosol types. The most recent version of the data based on Version 8 reprocessing has been released.

Recently, new methods have been developed to quantitatively detect aerosols using SeaWiFS visible channels over many types of land surfaces as well as the oceans. Because of the high spatial resolution (1 km) we are now able to investigate the sources of dust and smoke by combining the data with calculations from high-resolution transport models. An example of this type of analysis has been made showing dust flowing through mountain passes in Afghanistan and Iran. The aerosol data is also being used to assess the degree of radiative forcing (excess heating) in the atmosphere caused by the presence of dust. The results are used to estimate heating rates related to climate change. The dust aerosol sources and satellite derived winds have been incorporated in the GOCART model to map out trajectory plumes for any time of the day, and to give altitude distributions. One of the applications of the GOCART model to aerosol data is the estimation of air quality in the boundary layer. This is especially important in Africa where the intense boundary layer dust storms are implicated in the incidence of meningitis with epidemic proportions. The results are of intense interest to CDC and WHO. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Multiyear Global Surface Wind Velocity Data Set

The Special Sensor Microwave Imagers (SSM/I) aboard three Defense Meteorological Satellite Program (DMSP) satellites have provided a large data set of surface wind speeds over the global oceans from July 1987 to the present. These data are characterized by high resolution, coverage, and accuracy, but their application was limited by the lack of directional information. In an effort to extend the applicability of these data, the DAO developed methodology to assign directions to the SSM/I wind speeds and to produce analyses using these data. This methodology has been used to generate a 15-year data set (from July 1987 through June 2002) of global SSM/I wind vectors. These data are currently being used in a variety of atmospheric and oceanic applications and are available to interested investigators. For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

Global Precipitation

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing intra- and inter-annual climatic fluctuations on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory have led the GPCP effort to merge microwave data from low-Earth-orbit satellites, infrared data from geostationary satellites, and data from ground-based rain gauges to produce the best estimates of global precipitation.

Version 2 of the GPCP merged data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at World Data Center A (located at the National Climatic Data Center in Asheville, North Carolina) and at the Goddard Distributed

Active Archive Center (DAAC). Evaluation is ongoing for this long-term data set in the context of climatology, ENSO-related variations and trends, and comparison with the new TRMM observations. Development of data sets with finer time resolution (daily and 3-hr) is proceeding. A daily, global analysis for the period 1997–present has also been completed for the GPCP and is available from the archives. A quasi-global, 3-hr resolution rainfall analysis combining TRMM and other satellite data is being produced in real-time in an experimental mode. A research version of this 3-hr data set will soon be available (in late 2003) for the TRMM observation period from January 1, 1998, to the present. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

SHADOZ (Southern Hemisphere ADditional OZonesondes) Data Set

The SHADOZ (Southern Hemisphere Additional Ozonesondes) project was initiated in 1998 to end the lack of tropical ozone profile data. SHADOZ facilitates weekly launches at a dozen locations, collecting and disseminating data through a centralized archive at http://code916.gsfc.nasa.gov/Data_services/shadoz/. More than 1600 ozone and PTU (pressure-temperature-humidity) profiles are available in the archive. SHADOZ data are used to to enhance satellite ozone profile climatology and study tropical chemistry and dynamics. More details are given in an article in Section 5. highlights, under the Atmospheric Chemistry and Dynamics Branch section. For more information, contact Anne Thompson (Anne.M.Thompson@nasa.gov).

Multiyear Data Set of Satellite-based Global Ocean Surface Turbulent Fluxes

Information on the turbulent fluxes of momentum (or wind stress), latent heat (due to evaporation), and sensible heat at the air-sea interface is essential in understanding the interaction between the atmosphere and oceans, global energy and water cycle variability, and in improving model simulations of climate variations. In recognition of the importance of these fluxes in climate studies, the World Climate Research Program (WCRP)/Global Energy and Water Experiment (GEWEX) Radiation Panel has established an international SEA surface turbulent FLUX project, called SEAFLUX, with the primary objective of deriving the global data sets of sea surface turbulent fluxes from satellite observations.

The Special Sensor Microwave/Imager (SSM/I) on board a series of the Defense Meteorological Satellite Program (DMSP) spacecraft has provided global radiance measurements for sensing the atmosphere and the surface. Version 2 data set of Goddard Satellite-based Surface Turbulent Fluxes (GSSTF2), derived from the SSM/I radiance measurements, provides daily- and monthly-mean turbulent fluxes and some relevant parameters over global oceans for the period July 1987–December 2000 and the 1988–2000 annual- and monthly-mean climatologies of the same variables. These variables are wind stress, latent heat flux, sensible heat flux, 10-m wind speed, 10-m specific humidity, sea-air humidity difference, and the lowest 500-m bottom-layer precipitable water. Its spatial resolution is 1º x 1º lat-long. Evaluation is ongoing for this long-term data set in the context of climatology, ENSO-related variations and trends, as well as comparison with research quality in situ measurements, and other data sets of satellite retrievals and the atmospheric general circulation model (GCM) climate simulation/assimilation. The data set is archived at the Goddard Distributed Active Archive Center (DAAC) and is posted in the SEAFLUX Web site for intercomparison and climate studies. For more information, contact Shu-Hsien Chou (Shu-Hsien.Chou-1@nasa.gov).

Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA major responsibility for studying the ozone layer.

Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, and human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

An emerging area of research is to understand the transport of chemically active trace gases across the tropopause boundary. It has been suggested that changes in atmospheric circulation caused by greenhouse warming may affect this transport and, thus, delay the anticipated recovery of the ozone layer in response to phase-out of CFCs. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

Total Column Ozone and Vertical Profile

Laboratory for Atmospheres scientists have been involved in measuring ozone since April 1970 when a satellite instrument, the Backscatter Ultraviolet (BUV) Spectrometer, was launched on NASA's Nimbus-4 satellite to measure the column amount and vertical distribution of ozone. These measurements are continuing aboard several follow-on missions launched by NASA, NOAA, and, more recently, by the ESA.

An important activity in the Laboratory is developing a high-quality, long-term ozone record from these satellite sensors and comparing that record with ground-based and other satellite sensors. This effort, already more than a quarter century in duration, has produced ozone data sets that have played a key role in identifying the global loss of ozone due to certain human-made chemicals. This knowledge has contributed to international agreements to phase out these chemicals by the end of this century. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia@nasa.gov).

Surface UV Flux

The primary reason for measuring atmospheric ozone is to understand how the UV flux at the surface might be changing and how this change might affect the biosphere. The sensitivity of the surface UV flux to ozone changes is calculated using atmospheric models and the measured values of ozone, aerosol, and cloud amounts. Yet, until recently, we had no rigorous test of these models, particularly in the presence of aerosols and clouds. By comparing a multiyear data set of surface UV flux generated from TOMS data and high-quality ground-based measurements, especially those from a cooperative effort with the U.S. Department of Agriculture, we are increasingly successful in quantifying the respective roles of ozone, aerosols, and clouds in controlling the surface UV flux over the globe. The better agreement between satellite estimations of UV irradiance and ground-based measurements has improved confidence in UV flux estimates for regions that are not accessible to ground instruments (e.g., deserts, oceans, etc.). There are 5 new UV products available, the noontime irradiances at 305, 310, 324, 380 nm, and erythemal, in addition to the traditional erythemal daily exposure. We have recently extended the analysis of UV flux for penetration into the deep oceans and coastal regions using a newly developed UV radiative transfer model. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Data Assimilation

The DAO has taken on the challenge of providing to the research community a coherent, global, near real-time picture of the evolving Earth system. The DAO is developing a state-of-the-art Data Assimilation System (DAS) to extract the usable information available from a vast number of observations of the Earth system's many components, including the atmosphere, the oceans, the Earth's land surfaces, the biosphere, and the cryosphere (ice sheets over land or sea).

The DAS is made of several components including an atmospheric prediction model, a variational physical space analysis scheme, and models to diagnose unobservable quantities. Each of these components requires intense research, development, and testing. Much attention is given to ensuring that the components interact properly with one another to produce meaningful, research-quality data sets for the Earth system science research community. (See later section on Modeling). For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

Observing System Simulation Experiments

Since the advent of meteorological satellites in the 1960s, considerable research effort has been directed toward designing spaceborne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction. Observing system simulation experiments (OSSE) have played an important role in this research. Such studies have helped in designing the global observing system, testing different methods of assimilating satellite data, and assessing the potential impact of satellite data on weather forecasting.

At the present time, OSSEs are being conducted to (1) provide a quantitative assessment of the potential impact of currently proposed space-based observing systems on global change research, (2) evaluate new methodology for assimilating specific observing systems, and (3) evaluate tradeoffs in the design and configuration of these observing systems. Specific emphasis over the past year has been on space-based lidar winds and other advanced passive sensors. For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

Seasonal-to-Interannual Climate Variability and Prediction

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote-sensing data, historical climate data, model outputs, and assimilated data. Climate diagnostic studies will be combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include the El Niño Southern Oscillation (ENSO), monsoon variability, intraseasonal oscillation, and water vapor and cloud feedback processes. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, and nonlinear system analysis are used.

The Laboratory, in conjunction with the Laboratory for Hydrospheric Processes (Code 970), plays a lead role in NASA's Seasonal-to-Interannual Prediction Project (NSIPP). NSIPP promotes and facilitates collaboration between NASA and outside scientists in developing coupled ocean-atmosphere-land modeling system to predict El Niño events, and their impacts on climate of North America and other regions of the extratropics by utilizing a combination of satellite and in situ data. NSIPP will also employ a high-resolution atmosphere-land data assimilation system that will capitalize on a host of new high-resolution satellite data from MODIS/TERRA, AQUA and Landsat. This capability will allow scientists to better characterize the global and regional water cycles, and local and remote physical processes that control regional climates predictability. Another important activity is the use of satellite data for model validation and improving physical parameterizations, in particular with respect to clouds, radiation, and rainfall processes.

Promoting the use of satellite data for better interpretation, modeling and eventually prediction of geophysical and hydroclimate system is a top priority of research in the Laboratory. Satellite-derived data sets for key hydroclimate variables will be used extensively for diagnostic and modeling studies. Examples of such data sets are rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, land surface characteristics from the EOS TERRA, AQUA series, from TRMM, QuikSCAT and TOPEX/Poseidon and Jason-1, as well as from the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), SSM/I, MSU, and TOVS Pathfinder data. For more information, contact William Lau (William.K.Lau@nasa.gov).

Rain Measurements

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the Advanced Microwave Scanning Radiometer (AMSR) on EOS Aqua.

The retrieval techniques include the following: (1) A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations. (2) An empirical relationship that relates cloud thickness and other parameters to rain rates, using TOVS sounding retrievals. (3) An analysis technique that uses TRMM, other low-orbit microwave, geosynchronous infrared, and rain gauge information to provide a merged, global precipitation analysis. The merged analysis technique is now being used to produce global daily and quasi-global (50N-50S) 3-hourly analyses.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Rain Measurement Validation for the TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements is being established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Predicting Errors in Satellite Rainfall Measurements

A statistical model for the variability of rain in time and space, previously used to help understand the uncertainty in averages of satellite estimates of rainfall, can help with understanding the level of disagreement to be expected between satellite observations over areas containing rain gauges and the average rainfall measured by the gauges themselves. Such comparisons are desirable because they help to evaluate the accuracy of satellite rain estimates. The model suggests how best to choose the area around the gauges over which the satellite observations are averaged and the time intervals over which the gauge data are averaged in order to minimize the magnitude of the difference between the two averages. This was possible because the model captures an aspect of rain variability that many simpler models do not handle so well [T.L. Bell and P.K. Kundu, 2002]. An improved method of choosing the parameters in the model was also developed, and used to fit the model behavior to radar observations of rain in a major experimental campaign over the western equatorial Pacific, TOGA COARE [P.K. Kundu and T.L. Bell, 2003].

In a collaboration with researchers at Princeton, a simple method of estimating the error levels for maps of satellite average rainfall, previously developed and tested with rain observations from the Defense Meteorological Satellite Program satellites [T.L. Bell, P.K. Kundu, and C.D. Kummerow, 2001], was tested using ground-based observations of rain over the United States, and found to work quite well [M. Steiner, T.L. Bell, Y. Zhang, and E.F. Wood, 2003]. An effort is now under way to implement the method for the monthly rainfall maps produced by TRMM. For more information, contact Thomas L. Bell (Thomas.L.Bell@nasa.gov).

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei. These nuclei produce different drop size distributions in clouds, which, in turn, will affect the radiative balance of the atmosphere.

We developed algorithms to routinely derive aerosol loading, aerosol optical properties, and total precipitable water vapor data products from the EOS-Terra Moderate Resolution Imaging Spectroradiometer (MODIS). These algorithms are being evaluated, modified, and verified using the global MODIS data and information from the Aerosol Robotic Network (AERONET) of sun/sky radiometers. MODIS and AERONET data are being used to evaluate the global distribution of aerosols, their properties, and their radiative forcing of climate. Evaluation of the MODIS aerosol data with AERONET shows that they are as accurate as predicted in papers from 1997. Further evaluation involving monthly mean values of MODIS and AERONET, in conjunction with output from the GOCART aerosol transport model provides a comprehensive picture of the global aerosol system, and demonstrates a lack of bias in the MODIS monthly mean aerosol properties. MODIS and AERONET data used together enables the derivation of empirical phase functions without assumption of particle shape. These phase functions are fundamentally different from those derived from the common assumption of particle sphericity and will alter our perception of how irregularly shaped aerosol particles such as desert dust affect the amount of solar radiation back-scattered to space.

Laboratory scientists are actively involved in analyzing data recently obtained from national and international campaigns. These campaigns include the Puerto Rico Dust Experiment (PRiDE) which observed transported Saharan dust in the Caribbean, the Southern Africa Fire-Atmosphere Research Initiative (SAFARI) 2000 which characterized aerosols from southern African biomass burning, and the Chesapeake Lighthouse Aircraft Measurements for Satellites (CLAMS) which was an excellent opportunity to characterize both aerosol and various ocean surface conditions off the east coast of the United States. For more information, contact Lorraine Remer (Lorraine.A.Remer@nasa.gov).

Hydrologic Processes and Radiation Studies

Scientists in the Climate and Radiation Branch of the Laboratory are developing methods to estimate atmospheric water and energy budgets. These methods include calculating the radiative effects of absorption, emission, and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. Algorithms for global measurements of aerosol thickness are developed from MODIS data. Calibration/validation and scientific experiments on aerosols and clouds are conducted in various climatic regions of the world, with ground-based and airborne instruments, e.g., the SAFARI experiment in South Africa, PRiDE in Puerto Rico, ACE-Asia in central Asia. Also developed are arrays of highly mobile and versatile measurement platforms for direct measurements of surface radiation, water vapor and cloud properties for deployments in field campaigns, e.g., Surface Measurement of Atmospheric Radiation Transfer (SMART) and the off-beam lidar (THOR) for cloud thickness measurements.

Using long-term satellite and satellite-blended data and four-dimensional assimilated data, Laboratory scientists study the response of radiation budgets to changes in water vapor and clouds during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. Also investigated are the relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature. In addition, research effort is devoted to understanding and predicting the impacts of basin-scale sea surface temperature fluctuations such as the El Niño on regional climate variability over the Indo-Pacific region, North America, and South America. For more information, contact William Lau (William.K.Lau@nasa.gov).

Unified Onboard Processing and Spectrometry

Increasingly, scientists agree that spectrometers are the wave of the future in passive Earth remote sensing. But the difficulty stems from the vast volume of data generated by an imaging spectrometer sampling in the spatial and spectral dimensions. The data volume from an advanced spectrometer could easily require 10 times the present EOSDIS capacity—something NASA simply cannot afford. A group of scientists and engineers at GSFC, led by Si-Chee Tsay, is funded by ESTO/ACT, a new project to unify onboard processing techniques with compact, low-power, low-cost, Earth-viewing spectrometers being developed for eventual space missions. The philosophy is that spectrometry and its onboard processing algorithms must advance in lockstep, and eventually unite in an indistinguishable fashion. We envision a future in which archives of the spectrometer output will not be a monstrous data-dump of spectra, but rather the information content of those spectra, undoubtedly a much smaller and more valuable data stream. In the meantime, we must quickly find ways to losslessly onboard-compress spectra to the maximum extent possible. Our estimates indicate compressions of 10 to 100 are possible using a combination of physics-based removal and proximal differencing. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

Modeling

Modeling is an important aspect of our research, and is the path to understanding the physics and chemistry of our environment. Models are intimately connected with the data measured by our instruments: models are used to interpret the data, the data is combined with the models in data assimilation. Our modeling activities are highlighted below.

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, we must couple the atmospheric GCM with ocean- and land-surface models. Much of the work in this area is conducted in collaboration with Goddard’s Laboratory for Hydrospheric Processes, Code 970. The ocean models predict the global ocean circulation—including the sea surface temperature (SST)—when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation; transpiration through plants; infiltration; runoff; accumulation, sublimation, and melt of snow and ice; and groundwater budgets.

One of the main objectives of coupled models is forecasting seasonal-to-interannual anomalies such as the El Niño phenomenon. Laboratory scientists are involved in the NASA Seasonal-to-Interannual Prediction Project (NSIPP), which was established in collaboration with Goddard's Laboratory for Hydrospheric Processes. NSIPP's main goal is to develop a system capable of assimilating hydrologic data and using that data with complex, coupled ocean-atmosphere models to predict tropical SST with lead times of 6–14 months. A second goal is to use the predicted SST in conjunction with coupled atmosphere-land models to predict changes in global weather patterns.

NSIPP is currently producing routine seasonal forecasts. Each month surface and subsurface hydrographic data are assimilated to produce initial conditions for the ocean component of a coupled ocean-atmosphere-land forecast system. An ensemble of forecasts is then integrated for 1 year. In addition to this coupled forecast of SST, NSIPP also performs monthly "Tier 2" forecasts, using SSTs, predicted at other centers, to force more detailed atmospheric models. NSIPP's forecasts are available on the Internet at http://nsipp.gsfc.nasa.gov and are used by prediction centers for guidance in their assessments.

In addition to its forecasting work, NSIPP is engaged in research activities in land surface modeling, coupled processes, low-frequency atmospheric phenomena, and various aspects of data assimilation. More on this work can be found at the above Web site, together with a large archive of model-simulated data. For information, contact Max Suarez (Max.J.Suarez@nasa.gov).

Global Modeling and Data Assimilation

Development of the Data Assimilation System

In October 2002, the Data Assimilation Office transitioned to operations GEOS-4, its next generation data assimilation system for supporting the EOS Terra and Aqua missions. This new system consists of a completely redesigned state-of-the-art general circulation model based on the finite-volume dynamical core developed at DAO, coupled to physical parameterizations from National Centers for Atmospheric Research (NCAR). The system employs an adaptive statistical quality control, which examines the quality of the input data stream taking into consideration the "flow of the day." The system ingests data from a variety of conventional and remotely sensed data including rawinsondes, TOVS Level 1B radiances and scatterometers. In the core of the assimilation algorithm is DAO's Physical-space Statistical Analysis System (PSAS), a global 3-D VAR class solver that combines model short-term forecast with observations to provide an optimal estimate of the atmospheric state. Compared to the previous GEOS-3.2 operational system, the next generation system has superior forecasts skills, has an improved stratospheric circulation, realistically captures the evolution of synoptic systems, and has a competitive climate. For more information, contact Robert Atlas (Robert.M.Atlas@nasa.gov).

Cloud and Mesoscale Modeling

The mesoscale (MM5) and cloud-resolving (Goddard Cumulus Ensemble-GCE) models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones and frontal rainbands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, and vegetation and soil) effects on atmospheric convection, cloud-chemistry interactions, cloud-aerosol interactions, and stratospheric-tropospheric interaction. Other important applications include assessment of the potential benefits of assimilating satellite-derived water vapor, winds and precipitation fields into tropical and extra-tropical regional-scale (i.e., hurricanes and cyclones) weather simulations, and climate applications. The latter involves long-term integrations of the models that allow for the study of air-sea and cloud-radiation interactions and their role in cloud-radiation-climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy and radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical and mid-latitude weather systems.

Data collected during several major field programs, GATE (1974), PRESTORM (1985), TOGA COARE (1992–1993), ARM (1997), SCSMEX (1998), TRMM LBA (1999), TRMM KWAJEX (1999) and CAMEX3/4 (2000/2001), were used to improve as well as to validate the GCE and MM5 model. The MM5 was also improved in order to study regional climate variation, hurricanes and severe weather events (i.e., flash floods in the central United States and China). The models also are used to develop retrieval algorithms. For example, GCE model simulations are being used to provide TRMM investigators with four-dimensional cloud data sets to develop and improve TRMM rainfall and latent heating retrieval algorithms and moist processes represented in large scale models (i.e., weather forecast model and climate model). Four-dimensional latent heating structures (1º by 1º, monthly) were retrieved from December 1997 to November 2002.

The scientific output of the modeling activities was again exceptional in 2002 with 15 new papers published and many more submitted. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao-1@nasa.gov).

Physical Parameterization in Atmospheric GCMs

The development of submodels of physical processes (physical parameterizations) is an integral part of climate modeling activity. Laboratory scientists are actively involved in developing and improving physical parameterizations of the major radiative transfer moist processes, clouds and cloud radiation interaction and Earth-atmosphere interaction processes. All of these areas are extremely important for eliminating climate-model biases, which leads to a better understanding of the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

For atmospheric hydrologic processes, we are evaluating and improving a prognostic cloud liquid water scheme, which includes representation of source and sink terms as well as horizontal and vertical advection of cloud water substance. This scheme incorporates attributes from physically based cloud life cycles, including the effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity corrections. The boundary-layer clouds are consistently derived from and linked to boundary-layer convection. We are evaluating coupled radiation and the prognostic water schemes with in situ observations from the ARM-CART and TOGA-COARE IOPs as well as satellite data. For land-surface processes, a new snow physics package has been developed and evaluated with GEWEX GSWP data sets. It is currently in the GEOS/fv-NCAR GCMs. Moreover, the soil moisture prediction is extended down to 5m, which often goes through the groundwater table. All these improvements have been found to better represent the hydrologic cycle in a climate simulation. Currently, we are performing objective intercomparisons of different parameterization concepts applied to both models and satellite data retrievals within GSFC laboratories. NCAR/GISS scientists are our active collaborators. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional models to understand the behavior of ozone and other atmospheric constituents. We use the two-dimensional models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects, such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. Three-dimensional stratospheric chemistry and transport models (CTMs) simulate the evolution of ozone and trace gases that affect ozone. The constituent transport is calculated utilizing meteorological fields (winds and temperatures) generated by the DAO or using meteorological fields that are output from a general circulation model (GCM). These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and multiannual. The model simulations are compared with observations, with the goal of improving our understanding of the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability.

The modeling effort has evolved in four directions: (1) Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations. (2) Two-dimensional (2-D) noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multidecadal chemical assessment studies. (3) Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes. (4) Three-dimensional (3-D) CTMs have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport. The constituent fields calculated using winds from a new GCM developed jointly by the DAO and the National Center for Atmospheric Research exhibit many observed features. We are coupling this GCM with the stratospheric photochemistry from the CTM with the goal of developing a fully interactive 3-D model that is appropriate for assessment calculations. We are also using output from this GCM in the current CTM for multidecadal simulations. A pending improvement to the CTM is implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability will be needed for interpretation of data from EOS Aura, to be launched in early 2004.

The Branch uses trace gas data from sensors on the UARS, on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2-D or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

Support for National Oceanic and Atmospheric Administration Operational Satellites

In the preceding pages, we examined the Laboratory for Atmosphere’s work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA’s remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists assure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments flies on POES. Post-doctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA’s operational data.

Laboratory members are actively involved in the NPOESS Internal Government Studies (IGS) and support the Integrated Program Office (IPO) Joint Agency Requirements Group (JARG) activities. Likewise, the Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R. One scientist is involved in specifying the requirements for the advanced GOES-R atmospheric sounder, called High Resolution Environmental Suite (HES), writing the RFP, and serving on the Source Evaluation Board (HES).

Geostationary Operational Environmental Satellites

NASA GSFC project engineering and scientific personnel support NOAA for the GOES operational satellites. GOES supplies images and soundings to monitor atmospheric processes in real time, such as moisture, winds, clouds, and surface conditions. GOES observations are used by climate analysts to study the diurnal variability of clouds and rainfall and to track the movement of water vapor in the upper troposphere. The GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States to improve numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images via the World Wide Web (http://rsd.gsfc.nasa.gov/goes/). For more information, contact Dennis Chesters (Dennis.F.Chesters@nasa.gov).

Polar-Orbiting Environmental Satellites

Algorithms are being developed and optimized for the HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) first launched on NOAA 15 in 1998. Near real-time analysis will be carried out thereafter, as was done with HIRS2/MSU data. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Solar Backscatter Ultraviolet/2

NASA has the responsibility to determine and monitor the prelaunch and post-launch calibration of the SBUV/2 instruments that are included in the payload of the NOAA polar-orbiting satellites. We further have the responsibility to continue the development of new algorithms to determine more accurately the concentration of ozone in the atmosphere.

The NOAA 16 SBUV/2 instrument was launched and has gone through testing. It has now been operational since March 2001. Because the EP TOMS instrument is undergoing a degradation of its scanning mirror, the NOAA 16 SBUV/2 is now our primary measurement for the long-term ozone record. We are in the process of integrating the data from this instrument into our long-term record. This is being accomplished by comparing its data to both EP TOMS and the NOAA 11 SBUV/2 to evaluate their relative calibrations.

We have previously produced a single merged data set with a common calibration that extends from November 1978 through the end of 2000. We will soon be updating this record to include the NOAA 16 data that can continue into and beyond 2000. The data are available on the Web at http://code916.gsfc.nasa.gov/Data_services/merged/. For more information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov).

National Polar-Orbiting Environmental Satellite System

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board, acting as technical advisors. Laboratory personnel were involved in evaluating proposals for the OMPS (Ozone Mapper and Profiler System) and the Crosstrack Infrared Sounder (CrIS), which will accompany ATMS, an AMSU-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trade studies involving CrIS and ATMS, the advanced IR and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of AIRS to determine atmospheric

CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2 ppm (0.5%) from AIRS under clear conditions, total CH_4 to 1%, and total CO to 15%. This shows that AIRS should be able to produce useful information about atmospheric carbon. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

For OMPS, Laboratory scientists continue to support the IPO through the OOAT. The team conducts algorithm research and provides oversight for the OMPS developer. An algorithm is being developed to analyze SAGE III data when SAGE III operates in a limb-scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE/LORE shuttle mission conducted in 1997. The SOLSE/LORE payload was developed in the Laboratory for Atmospheres. The retrievals from this shuttle mission demonstrated the feasibility of employing limb scattering to observe ozone profiles with high vertical resolution down to the tropopause. This research is enabled by the advanced UV and visible radiative transfer models developed in the Laboratory. Laboratory scientists also participate in the Instrument Product Teams to review all aspects of the OMPS instrument development. The IPO supported a reflight of SOLSE/LORE on the space shuttle, in July 2002, as a risk mitigation effort related to the OMPS. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath-1@nasa.gov).

CrIS is a high-spectral-resolution interferometer infrared sounder with capabilities similar to those of the Atmospheric Infrared Sounder (AIRS). AIRS was launched with AMSU A and HSB on the EOS Aqua platform on March 5, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Preliminary results with AIRS/AMSU/HSB data indicate that the temperature sounding goals for AIRS, i.e., RMS accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, will be met. The AIRS soundings will be used in a pseudo-operational mode by NOAA/NESDIS and NOAA/NCEP. Simulation studies were conducted for the IPO to compare the expected performance of AIRS/AMSU/HSB with that of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements for CrIS to meet the NASA sounding requirements for the NPOESS Preparatory Project (NPP) bridge mission in 2005. Trade studies have also been done for the Advanced Technology Sounder (ATMS), which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Tropospheric wind profile measurements are the number one priority in the unaccommodated Environmental Data Records (EDR) identified in the NPOESS Integrated Operational Requirements Document (IORD-1). The Laboratory is using these requirements to develop new technologies and Direct Detection Doppler Lidar measurement techniques to measure tropospheric wind profiles from ground, air and spaceborne platforms. The IPO is supporting the effort through their IGS program. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

The IPO supports the development of Holographic Scanning Lidar Telescope technology as a risk reduction for lidar applications on NPOESS, including direct detection wind lidar systems. Currently used in ground-based and airborne lidar systems, holographic scanning telescopes operating in the visible and near infrared wavelength region have reduced the size and weight of scanning receivers by a factor of three. We are currently investigating extending the wavelength region to the ultraviolet, increasing aperture sizes to 1 meter and larger, and eliminating all mechanical moving components by optically addressing multiplexed holograms in order to perform scanning. This last development should reduce the weight of large aperture scanning receivers by another factor of three. For more information on the Holographic Optical Telescope and Scanner (HOTS) technology, visit the Web site at http://virl.gsfc.nasa.gov/lazer/index.html or contact Geary Schwemmer (Geary.K.Schwemmer@nasa.gov).

Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project scientist and the project manager, who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Table 3 lists project and deputy project scientists for current missions.

Table 3. Laboratory for Atmospheres Project and Deputy Project Scientists

Project Scientists		Deputy Project Scientists	
Name	**Project**	**Name**	**Project**
Pawan K. Bhartia	TOMS	Anne R. Douglass	EOS Aura, UARS
Dennis Chesters	GOES	Ernest Hilsenrath	EOS Aura
Jay Herman	Triana (renamed DSCOVR)	Arthur Hou	TRMM
		Si-Chee Tsay	EOS Terra
Robert Adler	TRMM	Marshall Shepherd	GPM
Charles Jackman	UARS		
Joel Susskind	POES		
Robert Cahalan	EOS SORCE		
Eric Smith	GPM		

EOS Validation Scientist		Field/Aircraft Campaign Co-Project/Mission Scientists	
Name	**Project**	**Name**	**Project**
David O’C Starr	EOS	Matt McGill	Cloud Sat
		Matt McGill	CALIPSO
		Robert Atlas	GTWS
		Judd Welton	MPLNET
		Si-Chee Tsay	ACE Asia II
		Robert Cahalan	THOR Validation
		Thomas McGee	N.Z. Intercomparison
		Geary Schwemmer	SERDR
		Bruce Gentry/Geary Schwemmer	HARGLO-2
		David Starr	CRYSTAL-FACE
		Belay Demoz	IHOP
		Paul Newman/Mark Schoeberl	SOLVE II

Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory relies on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities as well as those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities (see section 6 for more details on the education and outreach activities of our Laboratory). The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community, as shown in Appendix 5.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other Federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 7, reflects our many scientific interactions with the outside community; 70% of the publications involve co-authors from institutions outside the Laboratory.

A prime example of the collaboration between the academic community and the Laboratory is given in this list of collaborative relationships via memoranda of understanding or cooperative agreements. The Directorate list of these collaborations is given at the Web site http://webserv.gsfc.nasa.gov/ESD/collab.html.

- Center for Earth-Atmosphere Studies (CEAS), with Colorado State University;
- Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA), with Howard University;
- Cooperative Center for Atmospheric Science and Technology (CCAST), with the University of Arizona;
- Cooperative Institute for Atmospheric Research (CIFAR) Graduate Student Support, with UCLA;
- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- Earth System Science Interdisciplinary Center (ESSIC), with the University of Maryland, College Park;
- Goddard Earth Sciences and Technology Center (GEST Center), with the University of Maryland, Baltimore County, (and involving Howard University);
- Joint Center for Earth Systems Technology (JCET), with the University of Maryland, Baltimore County;
- Joint Center for Geoscience (JCG) at MIT;
- Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego; and,
- Joint Interdisciplinary Earth Science Information Center (JIESIC) with George Mason University.

These collaborative relationships have been organized to increase scientific interactions between the Earth Sciences Directorate at GSFC and the faculty and students at the participating universities. One means of increasing these interactions is a new initiative the Earth Sciences Directorate has established that will increase our sponsorship of graduate students. The Laboratory for Atmospheres is participating in this program, which will partner Laboratory scientists with graduate students. Our scientists will advise the student, serve on the thesis committee, visit the university, host the student at GSFC, and collaborate with the student's thesis advisor.

In addition, university and other outside scientists visit the Laboratory for periods ranging from 1 day to as long as 2 years. (See Appendix 1 for a list of recent visitors and Appendix 4 for seminars.) Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the Goddard Earth Sciences and Technology (GEST) Center. Visiting Scientists are appointed for up to 2 years and carry out research in preestablished areas. Visiting Fellows are appointed for up to 1 year and are free to carry out research projects of their own design. (See Appendix 3 for a list of NRC Research Associates, GEST Center Visiting Scientists, Visiting Fellows, and Associates of the Joint Institutes during 2002.)

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories.

Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other’s strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency’s scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/NSF Joint Center for Satellite Data Assimilation (JCSDA), which is building on prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

Interactions with Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the TRMM Mission, with the Japanese National Space Development Agency (NASDA); the Huygens Probe GCMS, with the ESA CNES; the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the VINTERSOL (Validation of International Satellites and study of Ozone Loss) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort.

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions to brief visits for giving seminars or working on joint science papers. As a result of the joint U.S.-Japan Workshop on Relationships and Intercomparison of Monsoon Climate Systems, held in our Laboratory in 2000, participants have agreed to develop pilot research projects involving the U.S. Global Change Research Program and the Japanese Frontier Research System for Climate Variability to enhance studies of teleconnections or globally connected climate systems.

Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government/industry partnerships, SBIRs, and technology transfer activities. In recent years two members of the Laboratory received the annual James J. Kerley Award for outstanding contributions to technology commercialization. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the micro-pulse Lidar and holographic optical scanner technology. Industry now uses these innovations for topographic mapping, medical imaging, and for multiplexing in telecommunications.

During the past year, two patents were issued to members of the laboratory. Matthew McGill and V. Stanley Scott were co-inventors of a novel Holographic Circle-to-Point Converter (HCPC). This invention has been awarded a patent (U.S. Patent #6,313,908) through GSFC. The HCPC is used to convert the output of Fabry-Perot interferometers into an easily measurable pattern. Specific applications include direct-detection Doppler lidar, airglow, and other measurements using Fabry-Perot interferometers as spectral resolving elements. The HCPC has been successfully demonstrated in a ground-based Doppler lidar system. The HCPC has been licensed through the GSFC Commercial Technology Office. For his work with the Commercial Technology Office in developing, licensing, and patenting the HCPC, Matthew McGill received the James J. Kerley Award for Technology Commercialization and Tech Transfer in 2000.

The United States Patent and Trademark Office issued a patent for Geary Schwemmer's invention titled "Methods and Systems for Collecting Data from Multiple Fields of View." This invention utilizes holographic optics to perform the function of a large aperture lidar receiver telescope that has several focal planes, each looking in a different direction with widely separated fields of view, as much as 90 degrees apart, and each obtaining use of the full aperture for photon collection. This system may eliminate or greatly minimize any mechanically moving systems to perform scanning of large angles, and will greatly reduce the weight of large aperture scanning lidar telescopes such as what is needed for atmospheric wind lidar measurements. This work followed on Geary's very successful previous work using rotating single holograms as conical scanning telescopes. The full text and figures of the patent are available on the Patent Office's Web page at http://www.uspto.gov/. Search for Schwemmer or the patent number: U.S. Patent No. 6,479,808 B1.

New research proposals involving technology development will have strong commercial partnerships wherever possible. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.